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# Engineering Geological Investigation of the Kırık Tunnel Route

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**Abstract**

Engineering structures are of great importance in the comfort and safe travel of people who prefer the highway in the existing transportation networks. Highway tunnels are one of the most important engineering structures that easily overcome transportation problems. This study investigates the geological and geotechnical structures of the Kırık tunnel on the Erzurum-Rize highway route, makes the rock mass classification required for tunnel excavation according to the New Austrian Tunneling Method and determines the tunnel support systems. Geological mapping, drillings, geological- geotechnical investigation based on in-situ and laboratory tests were carried out in order to reveal the physical and mechanical properties of the geological formations on the tunnel and to determine the basic data required by the project. It is divided into 4 classes on the basis of NATM Rock Classification along the tunnel axis. Rock support types related to rock classes defined as B1, B2, B3 and C2.

## 1. Introduction

On the Erzurum-Rize highway which is the main artery on the north-southeast axis in our country's road network, the passages connecting the Black Sea to Eastern Anatolia increase in the winter months due to the heavy snowfall of the road and the high tourism potential of Black Sea Region in the summer. By building a tunnel (Kırık tunnel) in sections where snowfall, icing and heavy snow are intense, the current Erzurum- Rize highway transportation is made safer for drivers.

The Kırık Tunnel is expected to contribute to the trade and tourism of the country as well as the convenience of transportation, by increasing the existing highway standard. Since the transportation between the Rize-Erzurum highway is reduced to 2 hours after the tunnel is opened for transportation, it is also aimed to facilitate the access of tourists from Black Sea to Erzurum, especially in winter for skiing.

The route had to be improved due to the frequent closure of the working area in winter due to snow and its type, and the high cost of maintenance and repair work for the road pavement that deteriorated due to freeze-thaw effects. For this reason, with the construction of the Kırık Tunnel, the use of this corridor more frequently and especially in the winter months and in the Kırık Tunnel, which is opened to increase the road standards between Erzurum and İspir, to examine the geological and geotechnical setting required for the tunnel and to classify the rock mass required for tunnel excavation. The geological and geotechnical model of the tunnel was created by correlating the geological unit and tunnel section profiles of the tunnel route. Rock mass rating (RMR), NGI Rock Tunnel quality index (Q system) and Geological Strength Index (GSI) rock mass classification systems according to New Austrian Tunneling Method) and tunnel support systems were determined.

## 2. Study Area

The study area is located on the Erzurum-Pazaryolu-İspir highway between Erzurum and İspir and is

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approximately 90 km away from Erzurum province. The Kırık tunnel is located on 1/25000 scale H45-b3 and H45-b2 map sheets (Figure 1). The tunnel on the route of the study area enters at Km: 64 + 730.00 and 2043.905 m elevations. Tunnel at Km: 71 + 826.00 (Right Line), Km: 71 + 843.00 (Left Line) and 1706.950m elevation, the tunnel is designed to be in line with the geometry of the road on which it is located, with two lanes in two separate tubes. The shortening of 33 km and its deactivation of the Gölyurt Pass with an altitude of 2,380 meters, which became a nightmare for travelers especially in the winter months, has become even more important with the opening of the Ovit Tunnel. Tunnel entrance Km: 64 + 730.00 and tunnel exit Km: 71 + 826.00 (Right Line) / Km: 71 + 843.00 (Left Line) and the tunnel length is 7096 meters for the right line and 7113 meters for the left line. Tunnel entrance is at 2043,905 m elevation and exit is at 1706,950 m elevation and the elevation difference is 336.955 meters. Each of the tunnels has two lanes with 8.0 meter height and 5.0 meter width.

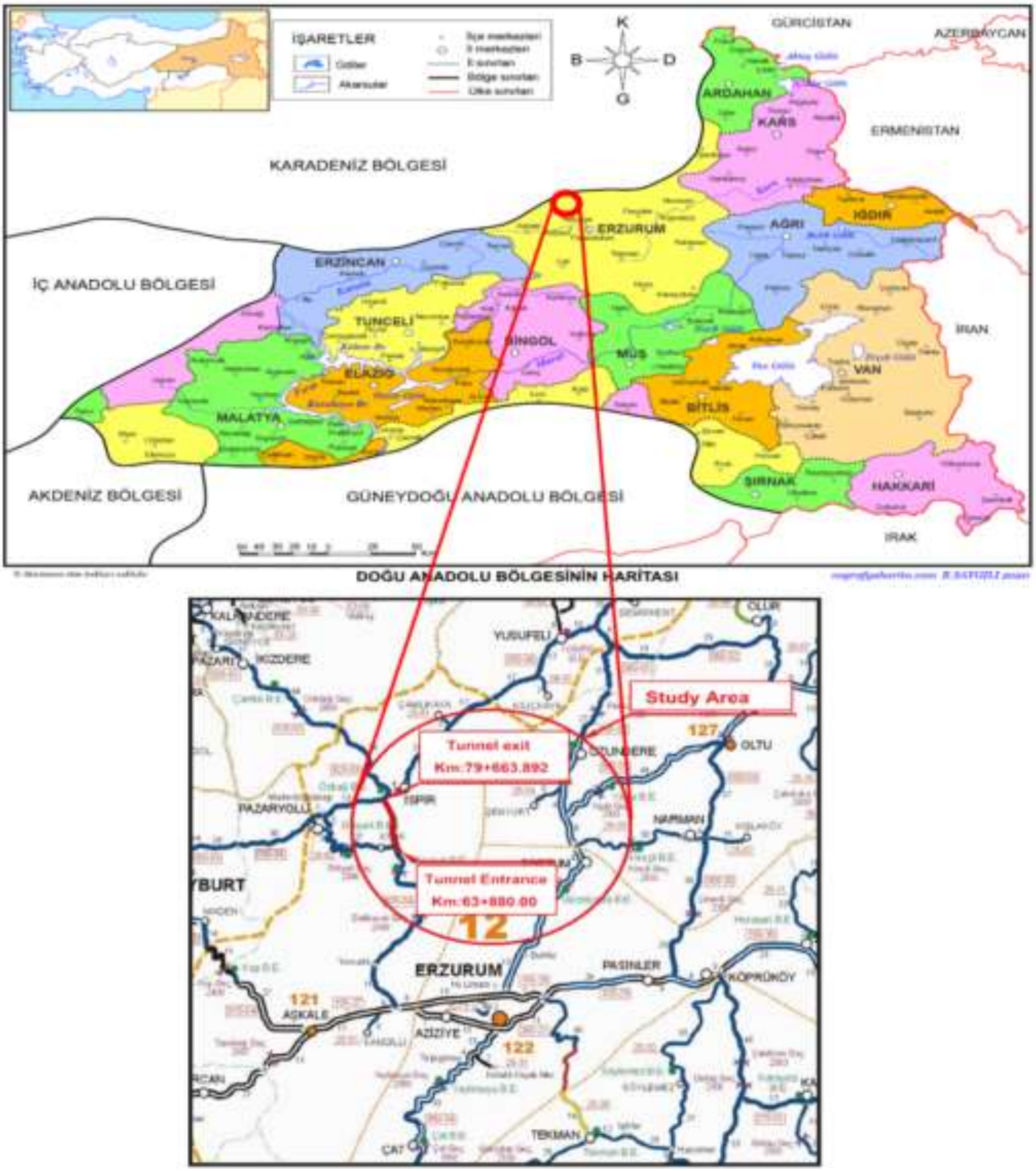


**Figure 1.** Study area location map

## 3. Geology of the Study Area

The formation and units seen in the tunnel route and its vicinity are from old to young. Karagüney formation consists of Jurassic-Cretaceous sandstone, sandy limestone, laminated chert and brecciated limestones at the bottom. The Hatungüney formation consisting of turbiditic sandstone, clayey limestone and limestones starts with clayey limestones, sandstones overlying the formation and formation consisting of conglomerate, sandstone, limestone alternation and clayey limestones. The Mescitdağları formation consisting of the alternation of Tertiary aged andesitic-basaltic rocks, agglomerate, tuff, tuffite, and volcanic of sandstone and mudstone is formed on these units [1]. Finally, Quaternary alluvium and slope debris overlies unconformably. Geology map of the studyarea is shown in Figure 2 (adapted from MTA 2002).

## 4. Tectonic Setting and Structural Geology of the Study Area

The Eastern Anatolia region, including the study area, has been under the control of the N-S oriented compressional stress since Late Cretaceous [2].

As the Neo-Tethys northern branch began to close in Late Cretaceous, the large ophiolite nappes were emplaced in the Senonian on the Anatolide / Tauride platform from this branch to the south. Before Late Eocene, with the collision of the Anatolide / Tauride platform and the Pontide island arc, the Eocene - Oligocene asymmetric flysch / molasse basins developed in front of the ophiolitic nappes advancing towards the south in the Eastern Anatolia Region [3].

In the Neotectonic period, as a result of compression in the region, high angle thrusts with EW strike or N dips, NW - SW trending left strike-slip faults, NW - SE striking right strike-slip faults, N - S striking tension cracks and widespread volcanic rocks emerging from these cracks have been formed [4].

During Late Miocene - Early Pliocene, the continental-continental collision between the Eurasian and Arabian plates caused the formation of a large number of left and right lateral faults, especially within the Eurasian plate. As is known, two of these faults of regional dimension are right-lateral North Anatolian and left-lateral East Anatolian faults [5].

The study area covers tectonic structures developed in compressional stress control since Late Cretaceous. An ophiolitic mixed Late Maastrichtian transgressive marine sequence that forms the basement in this area unconformably overlies [6]. This indicates that the first emplacement age of the ophiolite unit in the study area and its vicinity is pre-Late Maestrichtian. In the study area under the control of N - S directional compressive stress, approximately E-W trending thrust and large angle reverse faults, NE-SW trending left lateral and NW-SE trending right lateral strike-slip faults and approximately E-W axis trending folds were developed.

These tectonostratigraphy units with their NE – SW extentions in the study area and its immediate surroundings and which are defined as tectonostratigraphy units since they have different stratigraphic sequences, are in autochthonous or allochthonous positions according to their relative movements. Allochthonous units, which form a above each other structure by pushing on the autochthonous or another allochthonous slice along low angle thrust planes from these slices which are tectonically related with each other, have been distinguished in the style of "nap" masses in order to to express these features more clearly [7]. All of the faults determined in the study area are reverse faults and are seen intensely in the region between the tunnel exit and the end of the line.

## 5. Materials and Methods

Preliminary investigation studies have become an important issue within the scope of engineering geology studies to be carried out on the tunnel route. It is necessary to collect all necessary materials related to the field of study and its subject. In the field observations made on the tunnel route, slope debris derived from tuffite, carbonated siltstone and clayey limestone units was observed in the entrance the portal. The slope debris is completely weathered and the pebbles in the slope debris unit are of claystone origin. In the exit portal, there are units of clayey limestone origin in the slope debris and completely decomposed from the slope debris. In order to determine the problems that the rock masses in the study area may experience during tunnel boring, the status of the layers and discontinuities was tried to be determined. From the samples taken during the drilling studies, soil and rock coring samples were taken from in-situ test to detail the geological-geotechnical geological units on the tunnel route and to determine the engineering properties of the units in this section. In order to determine the index and engineering properties of the soil on it; Natural water content, Atterberg limits (liquid limit, plastic limit), plasticity index, grain size distribution (sieve analysis) tests were carried out.

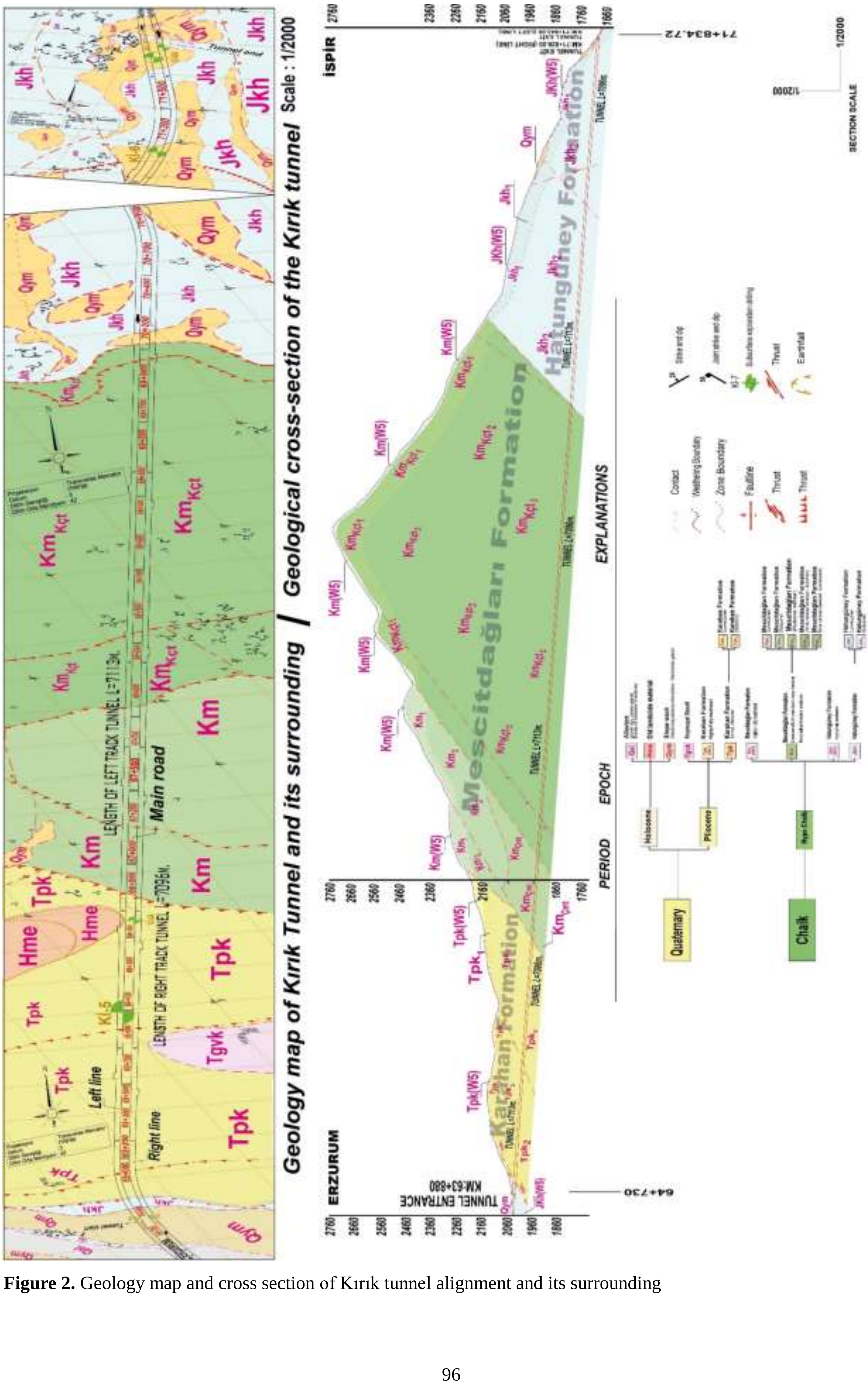


**Figure 2.** Geology map and cross section of Kırık tunnel alignment and its surrounding

In addition, to determine the basic parameters for tunnel design, rock mechanics tests were carried out from rock-specific units and the natural unit weight, uniaxial and triaxial compression tests in the rock were performed to reveal the mechanical and physical properties of the rock units. As a result, compressive strength, modulus of elasticity, poisson ratio values were determined.

In order to make the tunnel excavations safe, the geological units should be evaluated and support systems suitable for the excavation should be made according to the result of this assessment. While tunnel excavations can be done differently, different tunnelling methods have been developed depending on the way it is opened. Depending on the tunneling methods developed, it is important that the tunnel opening in the planned location can safely stay in the excavated area with support and maintain its purpose-based function. Tunnel excavations today can be excavated by using mechanical machinery and drilling-blasting method. Mechanical excavations are carried out by hydraulic breakers, arm tunnel boring machines, shielded machines, micro tunnel boring machines and various TBM (Tunnel Boring Machine) methods. The last method applied in the field of tunneling is NATM. NATM method is a method developed by taking advantage of the stability of the rock to hold itself.

The main purpose of NATM, which is opened without the use of a specific equipment, is to transform the environment surrounding the tunnel into a self-holding static system by controlling and directing the secondary stresses and deformations that will occur after the first excavation and consolidation [8].

Shotcrete, mesh steel, rock bolts and steel mesh, which are used as primary supports in NATM, form a composite structure together with the rock mass. This composite system, consisting of rock and support elements, provides the redistribution of the pressures around the tunnel, increasing the strength of the rock, which decreases as a result of loosening. Deformations occur in a controlled manner without collapsing or creating an unsafe environment in the tunnel [9].

As a result of the studies, suggestions were made for excavation and support systems with the help of the RMR, Q and NATM classification systems of the geological units on the route with the help of engineering geology data on the tunnel route.

## 6. Results and Discussion

The tunnel route is opened within the Late Jurassic Karagüney formation, Akçağıl formation and Lower Cretaceous Hatungüney formation, Mescitdağları formation and Quaternary Karahan formation and slope debris. The tunnel route is divided into 24 different zones (Structural zone) depending on the layer locations of the geological units, the cover height, the portal structures and the structural features of the tunnel route (Table 1).

**Table 1.** Dividing the tunnel route into structural zones

| KM | Formation | Lithology | Meter |
|---|---|---|---|
| 64+730-64+825 | Hatungüney Formation | JKh (W5) / $JKh_1$ | 95 |
| 64+825-64+945 | Karahan Formation | $Tpk_1$ | 120 |
| 64+945-65+480 | | $Tpk_2$ | 535 |
| 65+480-65+590 | | $Tpk_2$ | 110 |
| 65+590-66+250 | | $Tpk_2$ | 660 |
| 66+250-66+380 | Mescitdağları Formation | Kmçmt | 130 |
| 66+380-66+780 | | Kmçmt | 400 |
| 66+780-66+850 | | Kmkçt2 | 70 |
| 66+850-66+860 | Fault Zone | Kmkçt2 | 10 |
| 66+860-66+870 | Fault Zone | Kmkçt2 | 10 |
| 66+870-67+080 | Mescitdağları Formation | Kmkçt2 | 210 |
| 67+080-67+150 | | Kmkçt2 | 70 |
| 67+150-69+540 | | Kmkçt2 | 2390 |
| 69+540-69+550 | Fault Zone | Kmkçt2 | 10 |
| 69+550-69+630 | Hatungüney Formation | $JKh_2$ | 80 |
| 69+630-69+640 | Fault Zone | $JKh_2$ | 10 |
| 69+640-70+750 | Hatungüney Formation | $JKh_2$ | 1110 |
| 70+750-70+760 | Fault Zone | $JKh_2$ | 10 |
| 70+760-70+850 | Hatungüney Formation | $JKh_2$ | 90 |
| 70+850-71+070 | | $JKh_2$ | 229 |
| 71+070-71+600 | | $JKh_2$ | 530 |
| 71+600-71+720 | | $JKh_2$ | 120 |
| 71+720-71+760 | | $JKh_2$ | 40 |
| 71+760-71+834.72 | | $JKh_1$ | 74,72 |

Geological and geotechnical research studies were conducted to determine the ground conditions of Km: 63 + 880.00 - 71 + 834.72 of the proposed route belonging to the Kırık tunnel in the study area. Engineering geology mapping consists of foundation drilling and in – situ test, research and laboratory test.

A total of 728 meters of foundation drilling has been completed in 7 locations in order to detail the rock units in terms of geological and geotechnical aspects, determine the engineering characteristics of the units located in this section and determine the groundwater level, observed along the tunnel.

Pressiometer tests were carried out in the study area in order to determine the deformation properties of the soil and rock units observed in the foundation drillings. LouisMenard GA type pressiometer and 60 mm N type probe were used in the tests. For each drill, the variation of the deformation modulus (Em) and the limit (Pln) and net limit (PL*) pressures along the depth were determined. The deformation modulus values were found as 38 kg/cm$^2$ in minimum carbonated siltstones and 5186 kg/cm$^2$ in units with sandstone-clayey limestone-micrite alternation.

In order to determine the point load strength index value ($Is_{50}$) of the rock units in the study area, a point loading test was performed on the samples taken from the Kİ-5 and Kİ-6 boreholes. The test instrument consisting of loading system (loading body, loading pump and two conical ends), load indicator and measuring systems measuring the distance between conical ends are used. It is based on the principle of breaking the rock sample placed between two conical ends. As a result of the test performed on the samples the average point load strength index ($Is_{50}$) of the claystone unit is in the range of 0.41- 1.82 MPa, and the point load strength index of limestones ($Is_{50}$) is in the range of 11.44 - 14.14 MPa.

In order to determine the permeability of rock units constituting the tunnel floor, "Pressurized Water Tests (BST)" were carried out in the Kİ-5 and Kİ-6 boreholes. The test results calculated as "Lugeon" were shown in Table 2.

**Table 2.** Summary of pressurized water test results obtained in the study area

| Drilling Number | -Lugeon Values | Depth (m) | Lugeon classification | Units passed |
|---|---|---|---|---|
| Kİ-5 | | 122.00-126.00 | | *Karahan Formation* |
| Kİ-5 | 0.20 | 127.00-130.00 | Impermeable | *Karahan Formation* |
| Kİ-5 | | 132.00-135.00 | | *Karahan Formation* |
| Kİ-5 | 0.20 | 137.00-140.00 | Impermeable | *Karahan Formation* |
| Kİ-5 | 0.47 | 148.00-150.00 | Impermeable | *Karahan Formation* |
| Kİ-6 | 11.68 | 152.00-154.00 | Permeable | *Hatungüney Formation* |
| Kİ-6 | 0.10 | 157.00-159.00 | Impermeable | *Hatungüney Formation* |
| Kİ-6 | 1.42 | 162.00-164.00 | Low Permeable | *Mescitdağları Formation* |
| Kİ-6 | 2.01 | 167.00-169.00 | Low Permeable | *Mescitdağları Formation* |
| Kİ-6 | 3.45 | 172.00-174.00 | Low Permeable | *Mescitdağları Formation* |

It has been determined that the tunnel section and its immediate surroundings include slope debris (Qym), Karahan formation (Tpk), Mescitdağları formation (Km), Mescitdağları formation mudstone member ($Km_{çmt}$) and Hatungüney (Jkh) formation.

Karahan formation (Tpk) in general consists of claystone and sandstone units. The claystone unit is gray - greenish gray, little - medium hard, medium weak, locally weak, moderately weathered in places. Marine shells are distinguished in the unit and certain levels are completely weathered. The sandstone unit is green - greenish gray, friable - slightly hard, medium weak, moderately weathered and fine grained. The highly weathered level (Tpk / W5) of this unit is generally represented by a yellowish brown, pebbly sandy clay unit. It is moist-dry, plasticity-free, low-medium hard, angular, intense claystone / siltstone origin, with limestone origin blocks in places.

Mudstone member of Mescitdağları formation (Kmçmt), consists of mudstone and breccia. The mudstone member is generally red - burgundy -like - greenish colored, slightly hard - moderately hard, moderately weak - weak in places, moderately - severely weathered in places. Discontinuities cannot be traced due to segregation. The mudstone member of the Mescitdağları formation (Kmçmt) has generally impermeable - less permeable properties in terms of groundwater.

In general, Hatungüney formation (JKh), observed in the entrance and exit sections of the tunnel route and in a large part of the project route, consists of the intercalation of limestone, claystone, tuff, sandstone and clayey limestone. Limestone and clayey limestone unit in general; beige and gray colored, hard, medium resistant, slightly weathered. Discontinuities are in the range of 10° - 90° rough, dense - very dense, segmented and FeO colored. The claystone unit is beige-off-white colored, hard-medium hard, medium weak, slightly weathered. Discontinuities are 10° - 30° open, rough, dense - very dense, FeO colored, 0° - 90° closed and very dense. grayish dark brown, friable - slightly hard, weak - very weak, very - completely weathered.

Sandstones, medium hard with hard, medium weak, moderately weathered; Consists of friable - less hard, weakly weathered clayey limestones and medium hard - medium strength, slightly - moderately weathered limestones. Very - completely weathered level (JKh / W5) of this unit is silty sandy gravel and sandy gravel. The results of the laboratory tests performed on the SPT samples obtained from this level determined that they were GM, GP - GM, SC, SM, GP according to the Unified Soil Classification System.

The safe and economical underground excavations is directly proportional to the envisaged rock classification and related in tunnel support design. In today's modern in tunneling, the rock classifications, which are the basis for projecting, take into account the mass features of the rock. In this context, there are 3 important rock classifications in the main rock mass classifications developed and widely used in underground excavations in many different countries.

These classifications are; Rock Quality Index (Q) is the Geomechanical Classification of Jointed Rock Masses (RMR) and the Geological Strength Index (GSI) [12].

In the Q-classification, the Q-value takes values between 0.001 and 1000, covering the range between the worst rock condition and the perfect rock. Similarly, the RMR classification based on a score system ranging from 0-100 defines 5 rock classes from very good to very bad. In the GSI classification, it is expressed numerically in 25 categories (5 × 5), 5 depending on the structural characteristics of the rock mass, and 5 in terms of the state of the cracks and the degree of weathering (depending on the discontinuity surface).

GSI classification is preferred over RMR classification, especially in terms of engineering evaluations, due to its applicability to worst to best rock condition. GSI, which was initially associated with RMR and Q classification scores, has been used as a stand-alone classification system after 1999 with changes made in later years [10].

In the application of the RMR system, the rock mass in the study area is divided into structural sub-units and after determining the numerical values corresponding to each parameter separately according to the specific characteristics of the rock in the units, the total number of values is found and this number obtained is corrected according to the location of the discontinuities. The corrected total number is defined as the RMR rock mass number. RMR classification, the support type for each rock class, the cohesion of the tunnel rock and the internal friction angle, and the average standstill time can be predicted. RMR classification system was calculated according to [11], and rock classification was given according to the general result value for the rock units to be passed at the level of each different structural zoning tunnel separated due to different geological conditions along the route of the tunnel (Table 3).

**Table 3.** RMR classification system for tunnel route

| Km | Drilling Number | Geologial Unit | Rock Strength | RQD | Joint Frequency | Joint Status | [illegible] | Correction | RMR | Rock Class |
|---|---|---|---|---|---|---|---|---|---|---|
| 64+730-64+825 | KI-3 KI-4 | JKh /WS $JKh_1$ | 1 | 3 | 5 | 11 | 7 | -10 | 17 | Poor |
| 64+825-64+945 | | $Tpk_1$ | 2 | 8 | 5 | 13 | 7 | -6 | 30 | Poor |
| 64+945-65+480 | | $Tpk_2$ | 2 | 13 | 8 | 16 | 7 | -6 | 41 | Fair |
| 65+480-65+590 | | $Tpk_2$ | 2 | 3 | 5 | 9 | 7 | -6 | 21 | Poor |
| 65+590-66+250 | KI-5 | $Tpk_2$ | 2 | 13 | 8 | 16 | 7 | -6 | 41 | Fair |
| 66+250-66+380 | | Km | 2 | 3 | 5 | 9 | 7 | -6 | 21 | Poor |
| 66+380-66+780 | KI-5A | Km | 4 | 8 | 8 | 12 | 4 | -10 | 26 | Poor |
| 66+780-66+850 | | Km | 2 | 3 | 5 | 9 | 7 | -6 | 21 | Poor |
| 66+850-67+080 | | Km | 7 | 17 | 10 | 23 | 7 | -6 | 59 | Fair |
| 67+080-67+150 | | Km | 7 | 13 | 10 | 21 | 4 | -6 | 50 | Fair |
| 67+150-69+550 | | Km | 12 | 17 | 10 | 23 | 7 | -6 | 64 | Good |
| 69+550-69+630 | | $JKh_2$ | 2 | 8 | 8 | 13 | 4 | -5 | 30 | Poor |
| 69+630-70+760 | | $JKh_2$ | 12 | 13 | 10 | 23 | 7 | -5 | 60 | Good |
| 70+760-70+850 | | $JKh_2$ | 2 | 8 | 8 | 13 | 4 | -5 | 30 | Poor |
| 70+850-71+070 | | $JKh_2$ | 7 | 13 | 10 | 18 | 7 | -5 | 50 | Fair |
| 71+070-71+600 | KI-6 | $JKh_2$ | 12 | 13 | 10 | 21 | 7 | -5 | 58 | Fair |
| 71+600-71+720 | KI-6A | $JKh_2$ | 7 | 13 | 8 | 18 | 7 | -5 | 48 | Fair |
| 71+720-71+760 | KI-6A | $JKh_2$ | 4 | 8 | 8 | 18 | 4 | -5 | 35 | Poor |
| 71+760-71+834.72 | KI-7 | $JKh_1$ | 2 | 3 | 5 | 14 | 4 | -10 | 16 | Poor |
| **Km** | **Drilling Number** | **Geologial Unit** | **Rock Strength** | **RQD** | **Joint Frequency** | **Joint Status** | **[illegible]** | **Correction** | **RMR** | **Rock Class** |
| 66+850-66+860 | KI-5A | Fault Zone | 2 | 13 | 5 | 16 | 7 | -5 | 41 | Fair |
| 66+860-66+870 | | Fault Zone | 7 | 13 | 10 | 21 | 4 | -5 | 50 | Fair |
| 69+540-69+550 | | Fault Zone | 7 | 13 | 10 | 18 | 7 | -5 | 50 | Fair |
| 69+630-69+640 | | Fault Zone | 7 | 13 | 8 | 18 | 7 | -5 | 48 | Fair |
| 70+750-70+760 | | Fault Zone | 7 | 13 | 8 | 18 | 7 | -5 | 48 | Fair |

In the application of the Q system, the rock mass classification of the geological units in the tunnel opening was defined by the Q or NGI (Norwegian Geotechnical Institute) system. (1) Rock tunneling quality (Q) is calculated from the following expression as a function of 6 parameters independent of each other [10].

$$Q = \frac{RQD}{Jn} \cdot \frac{Jr}{Ja} \cdot \frac{Jw}{SRF} \tag{1}$$

(RQD / Jn) value; block size or size of the rock formed by different joint set, (Jr / Ja) value defines the roughness and friction between the joint surfaces and the filling material (shear strength between the blocks), (Jw / SRF) value indicates the effective stress (Table 4).

**Table 4.** Q classification system of the tunnel route

| Km | Drilling Number | Unit | RQD | Jn | Jr | Ja | Jw | SRF | Q | Rock Class |
|---|---|---|---|---|---|---|---|---|---|---|
| 64+730-64+825 | KI-3 KI-4 | JKh/WS $JKh_1$ | 20 (1A) | 2X12 (2G) | 1 (3E) | 3 (4D) | 0.66 (5B) | 10 (6B) | 0.018 | Extremely poor |
| 64+825-64+945 | - | $Tpk_1$ | 33 (1A) | 12 (2G) | 1.5 (3D) | 3 (4D) | 0.66 (5B) | 5.0 (6B) | 0.182 | Very poor |
| 64+945-65+480 | - | $Tpk_2$ | 50 (1C) | 12 (2G) | 1.5 (3D) | 2 (4C) | 0.66 (5B) | 2.5 (6C) | 0.825 | Very poor |
| 65+480-65+590 | - | $Tpk_2$ | 20 (1A) | 12 (2G) | 1.5 (3D) | 6 (4K) | 0.66 (5B) | 5.0 (6G) | 0.055 | Extremely poor |
| 65+590-66+250 | KI-5 | $Tpk_2$ | 70 (1C) | 12 (2G) | 1.5 (3D) | 1 (4B) | 0.66 (5B) | 7.5 (6D) | 0.770 | Very poor |
| 66+250-66+380 | - | Km | 20 (1A) | 12 (2G) | 1.5 (3D) | 6 (4K) | 0.66 (5B) | 5.0 (6G) | 0.055 | Extremely poor |
| 66+380-66+780 | KI-5A | Km | 35 (1A) | 12 (2G) | 1.5 (3D) | 3 (4D) | 0.66 (5B) | 10.0 (6A) | 0.096 | Extremely poor |
| 66+780-66+850 | - | Km | 20 (1A) | 12 (2G) | 1.5 (3D) | 6 (4K) | 0.66 (5B) | 5.0 (6G) | 0.055 | Extremely poor |
| 66+850-67+080 | - | Km | 80 (1D) | 12 (2G) | 1.5 (3D) | 1 (4B) | 0.66 (5B) | 1.0 (6J) | 6.600 | Fair |
| 67+080-67+150 | - | Km | 70 (1C) | 12 (2G) | 1.5 (3D) | 3 (4D) | 0.66 (5B) | 1.0 (6J) | 1.925 | Poor |
| 67+150-69+550 | - | Km | 85 (1D) | 12 (2G) | 1.5 (3E) | 1 (4B) | 0.5 (5C) | 1.0 (6J) | 5.311 | Fair |
| 69+550-69+630 | - | $JKh_2$ | 25 (1B) | 12 (2G) | 1.5 (3E) | 3 (4D) | 0.66 (5B) | 2.5 (6F) | 0.275 | Very poor |
| 69+630-70+760 | - | $JKh_2$ | 70 (1C) | 12 (2G) | 1.5 (3E) | 1 (4A) | 0.66 (5B) | 1.0 (6J) | 5.775 | Fair |
| 70+760-70+850 | - | $JKh_2$ | 35 (1B) | 12 (2G) | 1.5 (3E) | 6 (4K) | 0.66 (5B) | 2.5 (6F) | 0.193 | Very poor |
| 70+850-71+070 | - | $JKh_2$ | 55 (1C) | 12 (2G) | 1.5 (3E) | 1 (4B) | 0.66 (5B) | 2.5 (6F) | 1.815 | Poor |
| 71+070-71+600 | KI-6 | $JKh_2$ | 65 (1C) | 12 (2G) | 1.5 (3E) | 1 (4A) | 0.66 (5B) | 1.0 (6J) | 5.363 | Fair |
| 71+600-71+720 | KI-6A | $JKh_2$ | 60 (1C) | 12 (2G) | 1.5 (3E) | 1 (4B) | 0.66 (5B) | 2.5 (6F) | 1.980 | Poor |
| 71+720-71+760 | KI-6A | $JKh_2$ | 30 (1B) | 12 (2G) | 1.5 (3E) | 2 (4C) | 0.66 (5B) | 5.0 (6E) | 0.248 | Very poor |
| 71+760-71+834.72 | KI-7 | $JKh_1$ | 20 (1A) | 12X2 (2G) | 1.5 (3E) | 3 (4D) | 0.66 (5B) | 5.0 (6E) | 0.055 | Extremely poor |
| **Km** | **Drilling Number** | **Unit** | **RQD** | **Jn** | **Jr** | **Ja** | **Jw** | **SRF** | **Q** | **Rock Class** |
| 66+850-66+860 | KI-5A | Fault Zone | 70 (1C) | 12 (2G) | 1.5 (3D) | 1 (4B) | 0.66 (5B) | 7.5 (6D) | 0.770 | Very poor |
| 66+860-66+870 | | Fault Zone | 70 (1C) | 12 (2G) | 1.5 (3D) | 3 (4D) | 0.66 (5B) | 1.0 (6J) | 1.925 | Poor |
| 69+540-69+550 | | Fault Zone | 55 (1C) | 12 (2G) | 1.5 (3E) | 1 (4B) | 0.66 (5B) | 2.5 (6F) | 1.815 | Poor |
| 69+630-69+640 | | Fault Zone | 60 (1C) | 12 (2G) | 1.5 (3E) | 1 (4B) | 0.66 (5B) | 2.5 (6F) | 1.980 | Poor |
| 70+750-70+760 | | Fault Zone | 60 (1C) | 12 (2G) | 1.5 (3E) | 1 (4B) | 0.66 (5B) | 2.5 (6F) | 1.980 | Poor |

The geotechnical properties of the geological units on the tunnel route evaluated in terms of engineering geology are given in the table below (Table 5).

**Table 5.** Geotechnical characteristics of the geological units on the tunnel route

| Model Km | Geological Unit | C (kPa) | ϕ (°) | γ (kN/m³) | E (MPa) |
|---|---|---|---|---|---|
| 64+762 | Qym | 10 | 33 | 20 | 15 |
| | Jkh / W5 | 19 | 32 | 21 | 35 |
| | $Jkh_1$ | 88 | 50 | 25 | 640 |
| 64+900 | Tpk / W5 | 16 | 28 | 22 | 15 |
| | $Tpk_1$ | 47 | 35 | 23 | 70 |
| | $Tpk_2$ | 260 | 52 | 24 | 2170 |
| 66+240 | Tpk / W5 | 11 | 33 | 22 | 15 |
| | $Tpk_1$ | 39 | 37 | 23 | 70 |
| | $Tpk_2$ | 618 | 41 | 24 | 2170 |
| 66+780 | Km / W5 | 15 | 39 | 20 | 30 |
| | $Km_1$ | 70 | 29 | 22 | 170 |
| | $Km_2$ | 280 | 30 | 23 | 790 |
| | $Km_{çmt}$ | 960 | 38 | 25 | 4000 |
| 68+800 | Km / W5 | 20 | 34 | 20 | 30 |
| | $Km_{kçt1}$ | 461 | 47 | 25 | 7330 |
| | $Km_{kçt2}$ | 4698 | 44 | 27 | 33000 |
| 69+640 | Km / W5 | 13 | 39 | 20 | 30 |
| | $Km_{kçt1}$ | 404 | 49 | 25 | 7330 |
| | $Km_{kçt2}$ | 3500 | 53 | 27 | 45100 |
| | $Jkh_2$ | 2931 | 47 | 26 | 18100 |
| 70+850 | Jkh / W5 | 12 | 37 | 21 | 35 |
| | $Jkh_1$ | 131 | 45 | 25 | 640 |
| | $Jkh_2$ | 2141 | 52 | 26 | 18100 |
| 71+620 | Jkh / W5 | 12 | 37 | 21 | 35 |
| | $Jkh_1$ | 143 | 44 | 25 | 640 |
| | $Jkh_2$ | 1635 | 57 | 26 | 18100 |
| 71+721 | Qym | 10 | 33 | 20 | 15 |
| | $Jkh_1$ | 131 | 45 | 25 | 640 |
| | $Jkh_2$ | 1778 | 61 | 26 | 25600 |
| 71+780 | Qym | 10 | 33 | 20 | 15 |
| | $Jkh_1$ | 131 | 45 | 25 | 640 |

Rock masses with different geomechanical properties forming the ground profile of the tunnel route were evaluated based on Q and RMR rock classifications and the tunnel rock conditions were divided into 4 classes on the basis of NATM Rock Classification. The rock classes defined as B1, B2, B3 and C2 [13] were approximately 60%, 6% of the tunnel, respectively. Represents 20% and 14%. For the tunnel route where rock classification was made, the tunnel support systems were determined depending on the rock classes and rock classification.

The intervals of tunnel: Km: 66 + 870 - 67 + 080, Km: 67 + 150 - 69 + 540, Km: 69 + 640 - 70 + 750, Km: 71 + 070 - 71 + 600 were determined as B1 rock class within the Mescitdağları formation and the Hatungüney formation (JKh) As a result of the evaluation of rock conditions, The "B1" support type recommended for these sections is established from the following support elements.

Proposed support and excavation stages of support types were determined according to Q and RMR rock classification with mixed elements method.

• Shotcrete (ds = 100 mm)
• Wire mesh (1 layer), (Q221/221)
• Systematic bolt (L = 4.00 meter long, 2.00 x 2.00 meter spacing Φ28mm PG - bolt)

In B1 rock mass defined as “brittle”, the deformations are small and decrease very rapidly. The loosening of the rock caused by blasting and the low strength of the rock mass cause dismantling of the tunnel ceiling and the upper part of the side walls. Systematic bracing is required in limited areas in this rock class, and the implementation of the bracing outlined above is recommended.

The intervals of tunnel: Km: 67 + 080 - 67 + 150, Km: 70 + 850 - 71 + 070 and Km: 71 + 600 - 71 + 720 were determined as B2 rock class within the Mescitdağları formation and Hatungüney formation. As a result of the evaluation of rock conditions, "B2" support type recommended for these sections is established from the following support elements.

• Shotcrete (ds = 150 mm)
• Wire mesh (1 layer), (Q221/221)
• Systematic bolt (L = 4.00 meter long, 2.00 x 2.00 meter spacing Φ28mm PG - bolt)
• Continuing with 1.5 " injection when necessary

In B2 rock mass defined as "very brittle", if the support is done in time, the deformations decrease rapidly. If the support is not done in time or is not sufficient, there may be loosening and related ruptures in the B2 rock mass at the depths. It is recommended to apply the bracing outlined above on the tunnel ceiling, side walls and tunnel face to ensure stability.

The tunnel route designated as B3 rock class, for the tunnel Km: 64 + 945 - 65 + 480, Km: 65 + 590 - 66 + 250, Km: 69 + 550 - 69 + 630, Km: 70 + 760 - 70 + 850, and Km : 71 + 720 - 71 + 760 intervals formed within Karahan formation (Tpk), Mescitdağları formation (Km) and Hatungüney formation (JKh). The components of the "B3" support type suggested for these sections as a result of the evaluation of rock conditions are explained below.

• Excavation progress length maximum 1.25 - 1.50 m in the upper half and maximum 3.00 m in the lower half.
• The surface is covered with 2 cm shotcrete.
• Injected driving pipes are driven in every two shots.
• Steel mesh is placed Q589/221 tip
• Steel shoring is placed (NPI 140)
• Shotcrete thickness is completed to 13 cm.
• Second row steel mesh is placed Q589/221 tip
• Shotcrete is completed to 15 cm.
• Φ28mm PG bolts are placed

In the excavations made in B3 rock class, overbreak occurred in the rock mass. Fractured and weak rock with low cohesion created stability problems.

The intervals of the tunnel: Km: 64 + 730 - 64 + 945, Km: 65 + 480 - 65 + 590, Km: 66 + 250 - 66 + 850, Km: 71 + 760 - 71 + 834.72 were determined as C2 rock class within the Karahan formation (Tpk), Mescitdağları formation (Km) and the Hatungüney formation (JKh). As a result of the evaluation of rock conditions, the components of the "C2" support type suggested for these sections are explained below.

• Excavation progress length is maximum 1.00 m in the upper half, maximum 2.00 m in the lower half, 3.00 m in the base.

• Shotcrete (ds = 250 mm), The surface face covered with 3 cm shotcrete.

• Injected driving pipes are driven in every two shots.

• Steel mesh is placed Q589/221 tip

• Steel shoring will be placed (NPI 160)

• Sprayed concrete thickness is completed to 21 cm

• Second row steel mesh will be placed Q589/221 tip

• It will be covered with 4 cm more shotcrete and completed to a total of 25 cm.

• Φ28mm PG bolts are placed

• Base arch concrete

In terms of rock mass behavior, the C2 support class consists mainly of rocks disturbed by fault zones in the NATM standard. Even in split excavations (upper half - six half excavations), spillages occur in the rock mass. Less cohesion and less cementing cause insufficient stability of the the area to be excavated.

## 7. Conclusions

The Kırık tunnel is a double-tube road tunnel on the Erzurum- İspir (D925) state road at Km: 64 + 730.00- 71 + 826.00 (Right) / 71 + 843.00 (Left) of the main road project route. Geological mapping, foundation drillings, geological- geotechnical research based on in-situ and laboratory test were carried out in order to reveal the physical and mechanical properties of the geological formations on the tunnel passage route of the tunnel under construction, and to determine the data. Although units belonging to three different formations are passed along the designed tunnel passage on the surface, it is predicted that Mescitdağları formation can be seen mostly at the tunnel elevation. On the tunnel route the transition, no geological geotechnical negativity was encountered in large dimensions (landslide, liquefaction, settlement, etc.). Engineering geology definitions, drilling data and rock mechanics test results of the rocks, constituting the basis of rock classification and defined by kilometer intervals throughout the tunnel passage, have been evaluated and interpreted. In line with the engineering geology definition, the rock masses likely to be encountered at on the tunnel route were evaluated according to the Q and RMR Rock Classifications. It is divided into 4 classes on the basis of NATM Rock Classification along the tunnel pass. Rock support types related to rock classes defined as B1, B2, B3 and C2 have been proposed. The tunnel front support design was carried out as a result of the engineering geology definitions and rock classifications of the rocks along the tunnel route. Rock conditions indicate that tunnel excavation is generally appropriate to be done in the form of upper half / lower half. In addition, drilling-blasting method in the tunnel should be applied in sections with appropriate rock classification. In order to contribute to the safe and economical construction of the tunnel, it is necessary to determine possible stability problems, produce solution suggestions, and prepare a perimetric map of the tunnel in order to re-evaluate the rock class and support types foreseen in the project during excavation. Weak parts of the tunnel be built in C2 class, depending on the unfavorable geological conditions that could be encountered in faulted zones. Engineering geologic investigations provided necessary data for rock mass classification, developing geological model and support type along the tunnel axis for a safe and economical tunnel design.

## Conflict of Interests

No conflict of interest was stated by the authors.

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## Declaration of Ethical Standards

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and legal-special permission.

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